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LITHOLOGICAL AND TEXTURAL CONTROLS ON RADAR AND DIURNAL THERMAL SIGNATURES OF WEATHERED VOLCANIC DEPOSITS, LUNAR CRATER REGION, NEVADA

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1. INTRODUCTION

Radar backscatter intensity as measured by calibrated synthetic aperture radar (SAR) systems is primarily controlled by three factors: local incidence angle, wavelength-scale roughness, and dielectric permittivity of surface materials. Radar observations may be of limited use for geological investigations of surface composition, unless the relationships between lithology and the above characteristics can be adequately understood. In arid terrains, such as the Southwest U.S., weathering signatures (e.g. soil development, fracturing, debris grain size and shape, hill slope characteristics) are controlled to some extent by lithologic characteristics of the parent bedrock. These textural features of outcrops and their associated debris will affect radar backscatter to varying degrees, and the multiple-wavelength capability of the JPL AIRSAR system allows sampling of textures at three distinct scales.

Diurnal temperature excursions of geologic surfaces are controlled primarily by the thermal inertia of surface materials, which is a measure of the resistance of a material to a change in temperature (Gillespie and Kahle, 1977). Other influences include albedo, surface slopes affecting insolation, local meteorological conditions and surface emissivity at the relevant thermal wavelengths. To first order, thermal inertia variations on arid terrain surfaces result from grain size distribution and porosity differences, at scales ranging from micrometers to tens of meters. Diurnal thermal emission observations, such as those made by the JPL TIMS airborne instrument, are thus influenced by geometric surface characteristics at scales comparable to those controlling radar backscatter.

This paper is a preliminary report on a project involving a combination of field, laboratory and remote sensing observations of weathered felsic-to basaltic volcanic rock units exposed in the southern part of the Lunar Crater Volcanic Field, in the Pancake Range of central Nevada (Snyder et al, 1972). We focus here on the relationship of radar backscatter cross sections at multiple wavelengths, apparent diurnal temperature excursions identified in multi-temporal TIMS images, surface geometries related to weathering style, and parent bedrock lithology.

2. GEOLOGIC SETTING

The Lunar Crater portion of the Pancake Range consists of normal-faulted blocks of Tertiary rhyolitic to andesitic volcanic rocks, overlain in places by a Quaternary alkaline basalt field, which includes lava flows, cinder cones and maar craters (Scott and Trask, 1971; Snyder et al, 1972). The area described in this paper includes the southern portion of the basalt field, consisting of two lava flow complexes and two associated cinder cones. The Tertiary volcanic rocks in the area include andesitic and quartz latitic lavas, and a number of distinct welded and bedded tuff units, displaying varying phenocryst and lithic contents and devitrification textures (Snyder et al, 1972).

Basalt outcrops in the area show relatively mature upper weathered surfaces, with well-developed desert pavements consisting of basalt cobbles 1-10 cm in diameter resting on an aeolian-derived sediment of up to several m thickness. Felsic outcrop morphologies

are highly variable, ranging from low rounded hills with relatively thick debris mantles to cap-rocked mesas with fresh bedrock exposures and over-steepened cliff faces as high as 250 m. Alluvial deposits are predominantly sandy gravels, although several washes contain clasts up to large boulder size, reflecting high-energy depositional environments. Relationships at basalt flow margins indicate that these high valleys have been predominantly in a downwasting regime since the basalt eruptions.

3. REMOTE SENSING DATA

AIRSAR data for the southern Lunar Crater area includes three passes along the same azimuth, providing three incidence angles for many of the surfaces of interest. TIMS coverage consists of three sets of overlapping paired passes, acquired at approximately 4 a.m., 8 a.m. and 2 p.m. local time. Figure 1 shows a segment of the afternoon and pre-dawn Band 5 (10.3-11.1 μm) TIMS passes, along with an L-band HH polarization AIRSAR image of approximately the same area.

Changes in contrast relationships among surfaces between the afternoon and pre-dawn TIMS images are almost certainly related to thermal inertia variations. Comparison with the 8 a.m. image taken on the same day (not shown) indicates that differential heating related to slope/insolation effects is minimal by the late afternoon, and is certainly of negligible importance for the pre-dawn data. An interesting reversal in contrast is seen between adjacent outcrop areas of welded tuff (indicated by numbers 1 and 2). The southern outcrop (1) shows relatively little difference in emittance from the surrounding alluvial surfaces in both scenes, while the northern outcrop (2) is much darker in the afternoon scene and much brighter in the pre-dawn scene. Although these data have not yet been calibrated to extract temperature or thermal inertia estimates, qualitative examination indicates that the northern outcrop has a higher thermal inertia than the southern outcrop, expressed as a smaller excursion in temperature relative to the surroundings. AIRSAR data for these two surfaces suggest a relationship between outcrop morphology, surface roughness and thermal inertia. Figure 2 shows the behavior of radar cross section (σ_0) as a function of wave number ($2\pi/\lambda$) for several surfaces. The northern tuff outcrop exhibits high σ_0 values at all three AIRSAR wavelengths, while the southern outcrop has much lower values, and a strong dependence on wavelength. Field observations indicate that the northern outcrop is dominated by fresh exposures and high local relief, while the southern outcrop is pervasively fractured at the cm scale, leading to low relief and a mantle of cm-scale gravel debris. The diurnal temperature contrast is clearly related to the presence of the high thermal inertia rock exposures in the north and the low thermal inertia gravel debris in the south. Similarly, the AIRSAR signatures reflect the steep topography in the north, which leads to high σ_0 values independent of wavelength. On the southern outcrop, the surface appears smooth at P band and relatively rough at C-band, consistent with field observations of the roughness scale of the gravel debris. Although mapped by Snyder et al (1972) as a single unit, the two outcrops display dramatically different radar and thermal signatures related to weathering style. Further sample analysis should illuminate the lithological basis for the contrasting morphology.

At the "boulder field" site (3 in Fig.1), the presence of m-scale and larger boulders is probably responsible for the apparently higher thermal inertia (note bright "warm" signature in pre-dawn scene) of this deposit compared to the surrounding alluvium. This distinct roughness signature is reflected in the SAR data (bright patch in Fig.1), particularly at the longer wavelengths.

The "friable tuff" exposure (4 in Fig.1) consists of rounded "towers" of erodible fine-grained, possibly volcaniclastic tuff. Extensive patches of sandy debris shed from these exposures give the area an overall low thermal inertia, and an extremely smooth signature at C and L AIRSAR wavelengths. The unique radar and thermal signature of this unit is directly related to grain size and cementation, properties related to lithological and (volcanic or sedimentary) depositional parameters.

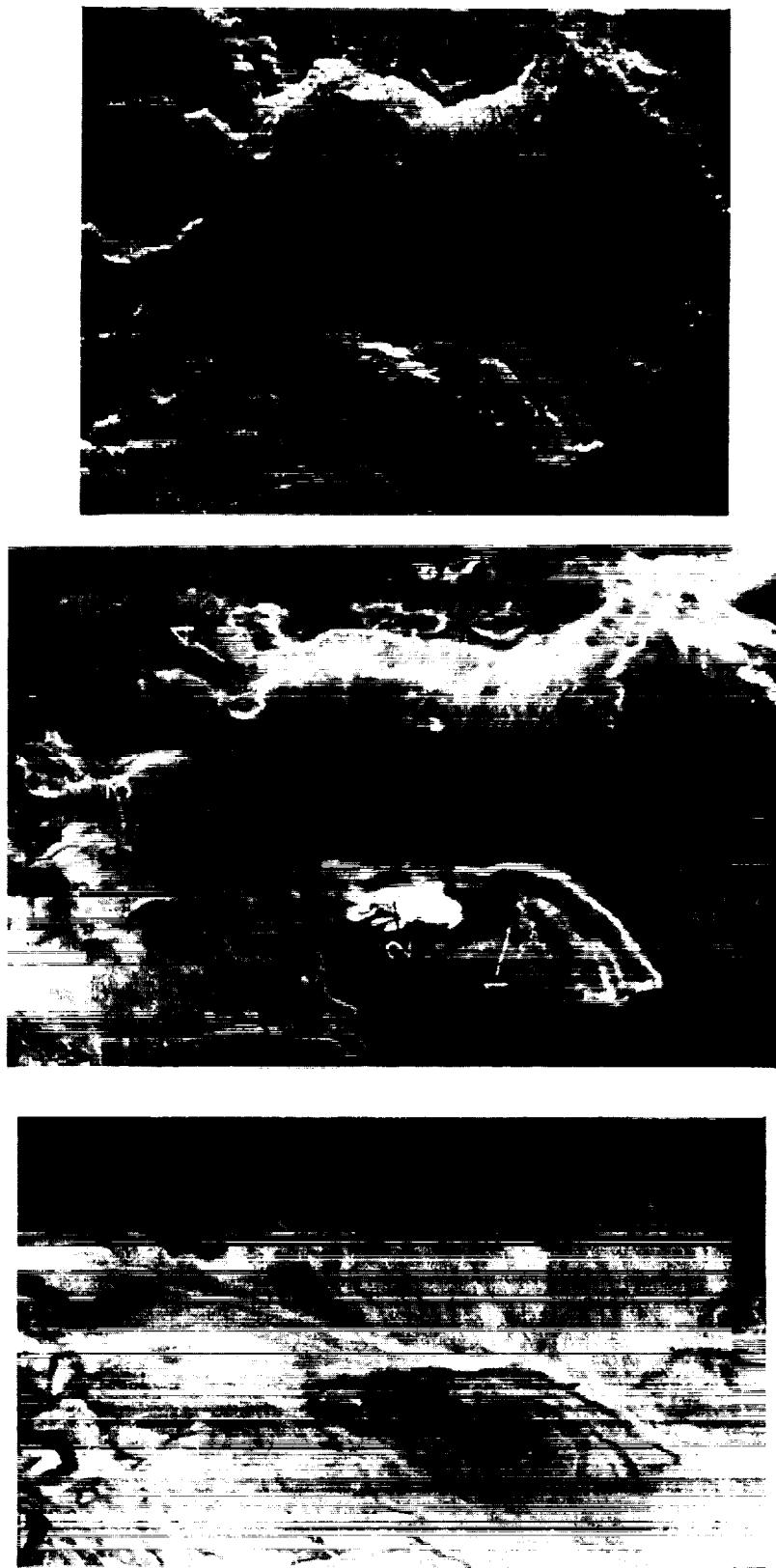


Figure 1. a) TIMS band 5 (10.3-11.1 mm) image, afternoon and b) pre-dawn, c) AIRSAR L-band HH, illumination from the left. Scene dimensions are approximately 3×5 km. Locations marked in b are 1) south tuff outcrop, 2) north tuff outcrop, 3) boulder field, 4) friable tuff.

4. CONCLUSIONS

Preliminary analysis of radar, thermal and field observations of the southern Lunar Crater region indicates that textural characteristics that dominate radar and diurnal thermal signatures of surfaces are related (though probably not uniquely related) to the primary outcrop lithology. Application of AIRSAR data may be of use in analysis of TIMS data, in which grain size and compositional influences on emittance must be separated. Such combined multi-sensor and field studies also provide valuable experience for analysis of purely "remote" datasets, such as Magellan and Mars Observer.

5. REFERENCES

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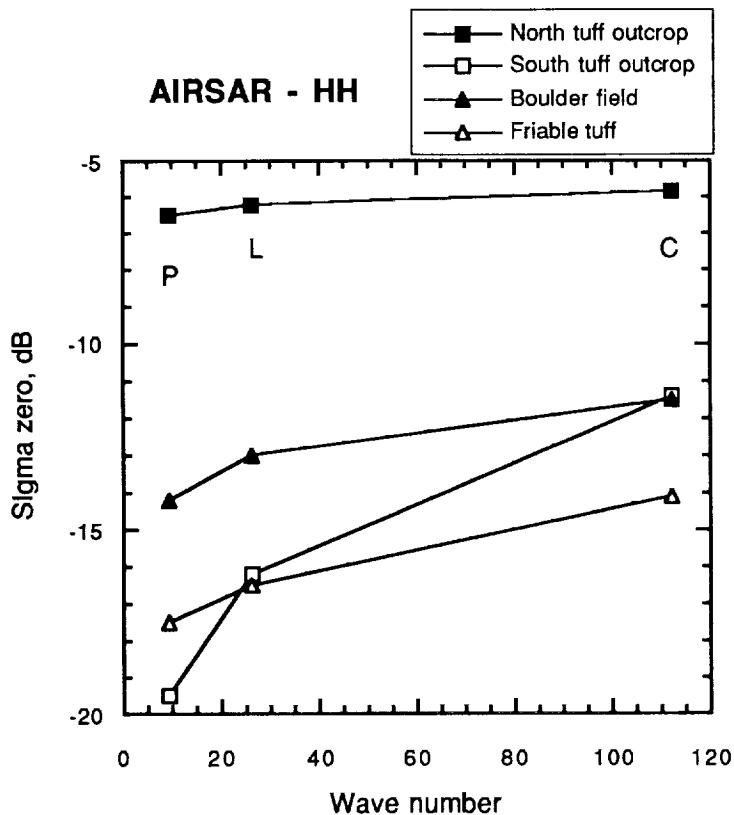


Figure 2. AIRSAR HH polarization backscatter cross section (σ_0) as a function of wave number ($2\pi/\lambda$). Corresponding wavelengths are: P-band 68 cm, L-band 24 cm, C-band 5.6 cm. Flat spectrum of north tuff indicates topographic control. Steep spectrum of south tuff indicates low "power" at larger scales of surface roughness.